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(71) Applicant(s)

Marconi Applied Technologies  
(Incorporated in the United Kingdom)  
One Bruton Street, LONDON, W1X 8AQ,  
United Kingdom

(72) Inventor(s)

Stephen John Taylor

(74) Agent and/or Address for Service

G Cockayne  
Marconi Intellectual Property, Waterhouse Lane,  
CHELMSFORD, Essex, CM1 2QX, United Kingdom

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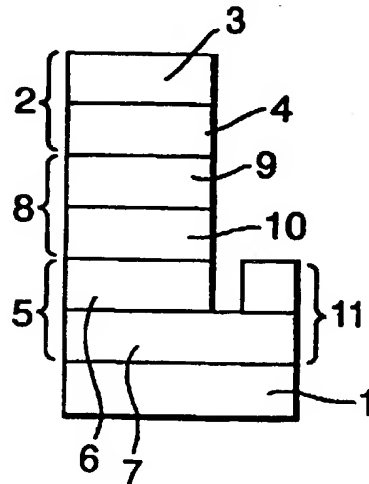
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(54) Abstract Title

Solar cell arrangements

(57) A solar cell arrangement includes a top cell (2), a tunnel diode (8) and a bottom cell (5) and a monolithically integrated protection diode (11). The protection diode (11) is formed by removing parts of the top cell (5) and tunnel diode (8) in a region. The solar cell arrangement may be a tandem or triple junction solar cell device.

Fig.1d.



At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

This print takes account of replacement documents submitted after the date of filing to enable the application to comply with the formal requirements of the Patents Rules 1995

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Fig.1a.

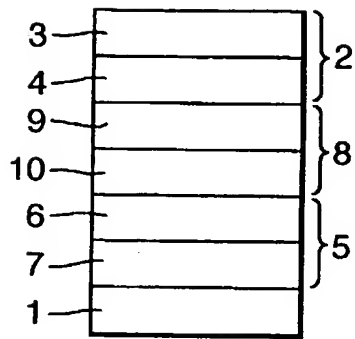


Fig.1b.

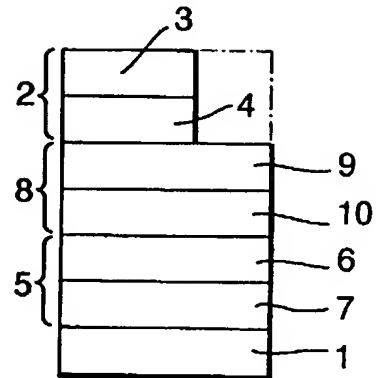


Fig.1c.

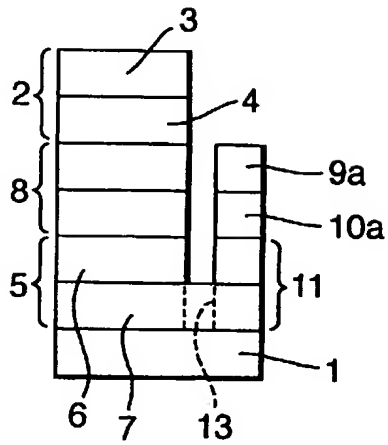


Fig.1d.

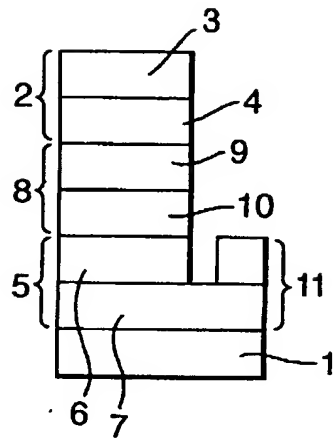


Fig.2a.

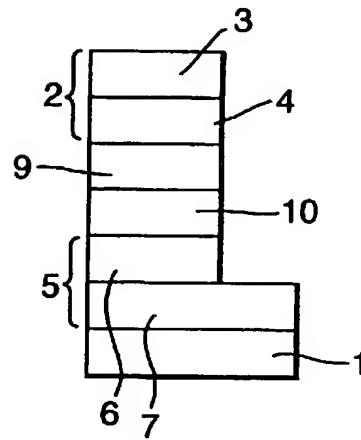


Fig.2b.

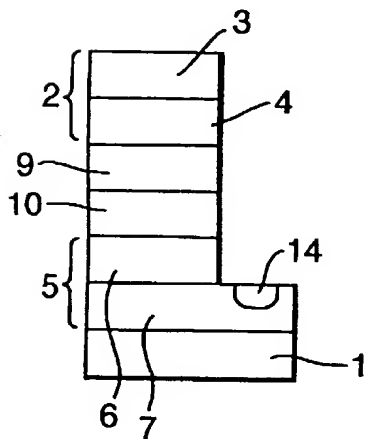


Fig.3.

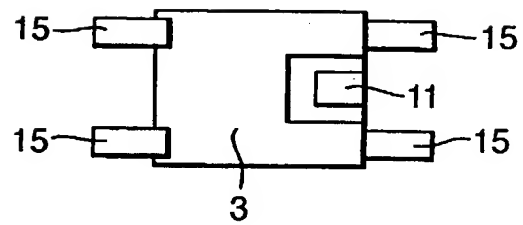


Fig.4a.

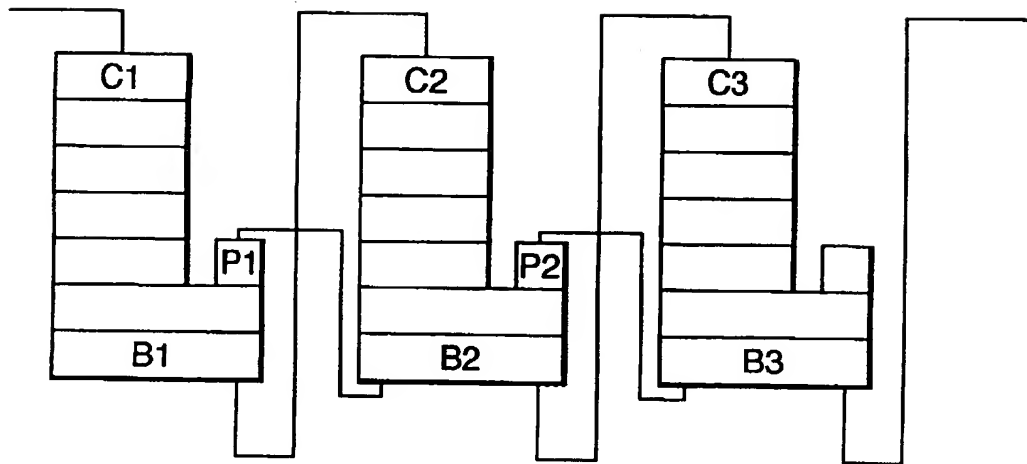
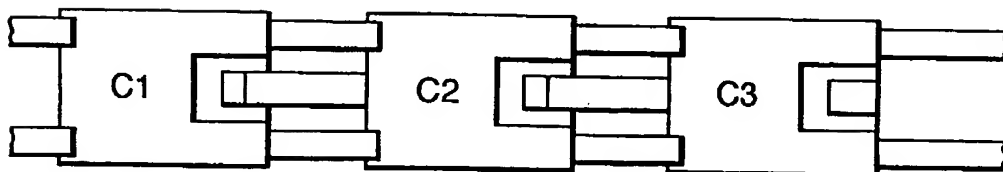


Fig.4b.



Solar Cell Arrangements

This invention relates to solar cell arrangements and a method of manufacturing such arrangements, and is more particularly concerned with the protection of solar cells against reverse current through them.

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In one type of solar cell (or photovoltaic cell), a voltage is developed across a p-n junction in a semiconductor when it is irradiated by photons. A plurality of solar cells may be connected together in an array to provide a power supply, such arrangements commonly being used in spacecraft and satellites for example. During operation, there may be circumstances where a single solar cell is shadowed or is faulty, and therefore not producing power, whilst the remainder of a string of cells with which it is connected in series is illuminated and producing power. This may lead to current being driven in reverse through the shadowed solar cell. Power is dissipated within the cell which is proportional to the reverse voltage across it. If the power density is sufficiently high, the cell may irreversibly break down.

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One way in which this problem may be alleviated is to use a protection diode wired across one or several solar cells in reverse parallel with them. If one of the cells across which it is connected is driven into reverse bias, the protection diode diverts current from the cell. This limits the power dissipation in the shadowed cell by both limiting the voltage across the shadowed cell and by passing the reverse current.

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The present invention is particularly concerned with multijunction solar cells in which a plurality of pn junctions are arranged vertically, such as tandem solar cells and triple junction cells. A tandem solar cell is one which includes two p-n junctions connected in

series internally by a tunnel junction or some other means. The front p-n junction produces voltage in response to incident radiation of a relatively short wavelength and the rear p-n junction is tailored for longer wavelengths, giving improved efficiency compared to an equivalent single solar cell device. A triple junction solar cell includes three single-junction  
5 cells with different energy band gaps which are stacked on one another.

According to a first aspect of the invention, a method of manufacturing a solar cell arrangement includes the steps of: producing a top solar cell structure in series with a bottom solar cell structure on a substrate; then removing part of one of the solar cell structures from a  
10 region; and defining a protection diode in the region.

Use of the method in accordance with the invention enables a protection diode to be monolithically incorporated into a multijunction solar cell device, such as a tandem solar cell or a triple junction solar cell. The protection diode may advantageously be defined following  
15 removal of part of the top solar cell structure but in other methods in accordance with the invention, this may be done prior to such removal.

In a tandem cell, the top and bottom cells are sensitive to different parts of the incident light spectrum, and the voltages that they generate are added to give the output  
20 voltage of the device as a whole. This is desirable for the solar cell. However, the invention leads to additional improved performance. By removing part of the top solar cell structure in the region where the protection diode is defined, it means that less power is dissipated in the protection diode than if the top solar cell structure were incorporated into the protection diode. In the latter case, at a given current, the voltage is higher and thus more power is

dissipated in the protection diode, increasing the risk of damage to the device as a whole. Thus the removal of one or more of the constituent diodes of a multijunction structure in accordance with the invention gives a significant advantage.

5           The top cell absorbs the shorter wavelength light from the available spectrum and thus the semiconductor material which forms the top cell must have a wider band gap than the semiconductor material which forms the bottom cell. Thus a protection diode made from material forming the "top cell" structure would operate at a higher voltage at a given current than one made from "bottom cell" material. As discussed above, operation at a lower voltage  
10 is desirable and may be achieved using the invention.

          Preferably, the top solar cell structure is removed from the region, to realise these advantages, although in alternative methods the bottom cell structure may be etched away from the back to form the protection diode from the structure with the wider band-gap.

15           Advantageously, a tunnel diode provides a connection between the top solar cell structure and the bottom solar cell structure, although other interfaces may be used instead. Where a tunnel diode is included, epitaxial layers making up the tunnel diode may also be left in the region where the protection diode is defined. Where tunnel diode layers are included in  
20 the region, external electrical connections may be made to the protection diode via them.

          In one method in accordance with the invention, the protection diode includes a layer or layers which also in other parts of arrangement form the bottom solar cell structure. In an alternative arrangement, the emitter of the bottom solar cell structure may be removed and

dopant introduced into the base of the bottom solar cell structure to define the protection diode. In another method, part of the base of the bottom solar cell structure may be removed and dopant introduced into the substrate to define the protection diode.

5           According to a feature of the invention, a solar cell arrangement comprises a top solar cell structure in series with a bottom solar cell structure on a substrate and a protection diode formed monolithically therewith in a region of the arrangement which does not include part of one of the solar cell structures. Preferably, it is part of the top solar cell structure which is not included.

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          According to a second aspect of the invention, a solar cell array comprises a plurality of solar cell arrangements in accordance with the invention

          Some ways in which the invention may be performed are now described by way of  
15       example with reference to the accompanying drawings in which:

          Figures 1a to 1d are explanatory diagrams relating to one method in accordance with the invention;

20       Figure 2a and 2b schematically illustrate another method in accordance with the invention:

          Figure 3 illustrates in plan view a solar cell devices in accordance with the invention;  
and



Figures 4a and 4b illustrate an array of solar cell devices.

To manufacture a photovoltaic cell in accordance with the invention, first of all a substrate 1, which in this case is of GaAs, is taken and a plurality of epitaxial layers are grown on it to define a tandem cell structure. This includes a top solar cell 2 having a top cell emitter 3 and a top cell base 4 connected in series with a base solar cell 5 having a bottom cell emitter 6 and a bottom cell base 7, the two solar cells 2 and 5 in this method being separated by a tunnel diode 8 comprising a tunnel diode emitter 9 and a tunnel diode base 10 to provide an ohmic connection between the two solar cells 2 and 5 to connect them in series.

With reference to Figure 1b, following deposition of the epitaxial layers, a region of the epitaxial top cell emitter 3 and top cell base 4 are removed by etching. As shown in Figure 1c, a trench is then etched to the bottom cell base 7 to define and isolate a protection diode 11. In one method in accordance with the invention, electrical contacts are then added so that external connection may be made to the top cell emitter 3, to bottom cell base 7 or substrate 1 (which are electrically equivalent) and to the protection diode 11 via the tunnel diode emitter 9a. The tandem cell so defined and its associated protection diode may then be incorporated in an array.

In a variant of the method, following removal from the region of the top solar cell 2, one or both of the tunnel diode emitter layer and base layer 9a and 10a may be removed from the same region. Figure 1d shows a device in which both layers 9a and 10a have been removed. Following this step, electrical connection is made to the tunnel diode base 10a or to the bottom cell emitter 6 respectively to make external connection to the protection diode 11.

The trench shown in Figure 1c may alternatively be etched to the conducting substrate 1 as indicated by the broken line 13.

In these methods, the epitaxial layers of the cell structure and protection diode are deposited simultaneously.

In another method in accordance with the invention, following the deposition of a plurality of epitaxial layers on a substrate to define a tandem solar cell structure, as shown in Figure 1a with an intermediate tunnel diode, in a region of the structure, the top solar cell 2 and tunnel diode 8 are etched away, as is part of the bottom cell emitter layer 6 as shown in Figure 2a. Following this step, local diffusion of a p-type (or n-type) dopant into n-type (p-type) material is carried out to define the emitter 14 of the protection diode as shown in Figure 2b. In an alternative method, part of the bottom solar cell base is also etched away and dopant introduced into the substrate to form the protection diode.

In one tandem solar cell in accordance with the invention, electrical contacts 15 are bonded to the structure shown in Figure 1d to form a solar cell device which is shown in plan view in Figure 3. A plurality of tandem solar cells are connected in series as shown in Figures 4a and 4b showing side and plan views respectively. Connections are made from the bottom cell base or substrate of one solar cell device to the top cell emitter of the adjacent solar cell device. The protection diode P1 of one solar cell device is electrically connected to the base of the bottom solar cell of an adjacent device.

The invention may be applied to a triple junction solar cell, in which the top and

middle solar cell structures, for example, may be etched away, together with any intervening tunnel diode layers, and the protection diode formed in the region.

Claims

1. A method of manufacturing a solar cell arrangement including the steps of: producing a top solar cell structure in series with a bottom solar cell structure on a substrate; then  
5 removing part of one of the solar cell structures from a region; and defining a protection diode in the region.
2. A method as claimed in claim 1 wherein part of the top solar cell structure is removed from the region.
- 10 3. A method as claimed in claim 1 or 2 wherein the protection diode is defined following removal of part of the top solar cell structure.
4. A method as claimed in claim 1, 2 or 3 and including the step of producing a tunnel diode  
15 between the top solar cell structure and the bottom solar cell structure.
5. A method as claimed in claim 4 and including adding external electrical connection means to the tunnel diode emitter in the region for connection of the protection diode.
- 20 6. A method as claimed in claim 4 and including the step of removing part of the tunnel diode emitter from the region.
7. A method as claimed in claim 6 and including adding external electrical connection means to the tunnel diode base in the region to provide electrical connection to the protection diode.

15. A method as claimed in any of claims 1 to 13 wherein the solar cell arrangement is a triple junction solar cell device.

16. A method as claimed in any preceding claim and including the step of connecting the arrangement to another arrangement with the protection diode being electrically in parallel with said another arrangement.

17. A solar cell arrangement manufactured in accordance with a method as claimed in any preceding claim.

18. A solar cell arrangement comprising a top solar cell structure in series with a bottom solar cell structure on a substrate and a protection diode formed monolithically therewith in a region of the arrangement which does not include one of the solar cell structures.

19. An arrangement as claimed in claim 18 wherein the region does not include the top solar cell structure.

20. A solar cell arrangement as claimed in claim 18 or 19 and including a tunnel diode between the top and bottom solar cell structures.

21. A solar cell arrangement as claimed in claim 18, 19 or 20 wherein the protection diode comprises an emitter layer on part of the base of the bottom solar cell structure.

22. An arrangement as claimed in claim 21 and including at least one of a tunnel diode

emitter and tunnel diode base layer on the emitter layer of the protection diode.

23. An arrangement as claimed in claim 18, 19 or 20 wherein the protection diode includes a doped region of at least one of the bottom solar cell base and the substrate.

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24. A solar cell array comprising: a plurality of solar cell arrangements as claimed in any one of claims 18 to 23.

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19. A method substantially as illustrated in and described with reference to the accompanying drawings.

20. A solar cell arrangement substantially as illustrated in and described with reference to Figures 1b, 1c, 1d, 2b or 3 of the accompanying drawings.

15

21. A solar cell array substantially as illustrated in and described with reference to Figures 4a and 4b of the accompanying drawings.



Application No: GB 0001601.4  
Claims searched: all

Examiner: Claire Williams  
Date of search: 27 April 2000

**Patents Act 1977**  
**Search Report under Section 17**

**Databases searched:**

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK CI (Ed.R): H1K (KECA, KPAC, KEAP)

Int CI (Ed.7): H01L (23/62, 27/142, 31/02, 31/042, 31/05, 31/068, 31/072, 31/075, 31/18)

Other: ONLINE: WPI, EPODOC, JAPIO

**Documents considered to be relevant:**

Category	Identity of document and relevant passage	Relevant to claims
Y	EP0369666 A1 (MITSUBISHI) whole document	1 - 4, 8, 11, 13, 14, 17 to 20
X, P	WO99/62125 A1 (TECSTAR POWER SYSTEMS) whole document and in particular Figure 14B	1- 4, 8, 13 to 15, 17 - 20 and 24
Y	US 5405453 (HO ET AL) whole document	1 - 4, 8, 11, 13, 14, 17 to 20
X	JP 090064397 (CANON) in particular the English PAJ abstract	1, 14 and 18

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